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(54) Measuring device.

(57) The measuring device comprises a detector (1) for a quantity x to be measured, which detector is adapted to produce two signals I_1 and I_2 which relate to x as $x = (I_1 - I_2)/(I_1 + I_2)$.
The device furthermore comprises a processing circuit (3) which includes a first and a second logarithmic converter (9, 11) whose inputs receive input signals V_1 and V_2 which are proportional to the first and the second measuring signal I_1, I_2, respectively. The outputs of the logarithmic converters (9, 11) are connected to first and second inputs (12A, 12B) of a subtractor circuit (13) which produces, on its output 14, an output signal U(x) which depends on the quantity x to be measured. If the subtractor circuit (13) is adapted to determine the hyperbolic tangent of the difference between the signals $\log V_1$ and $\log V_2$ present on its two inputs (12A, 12B), the relationship between u(x) and x will be linear.

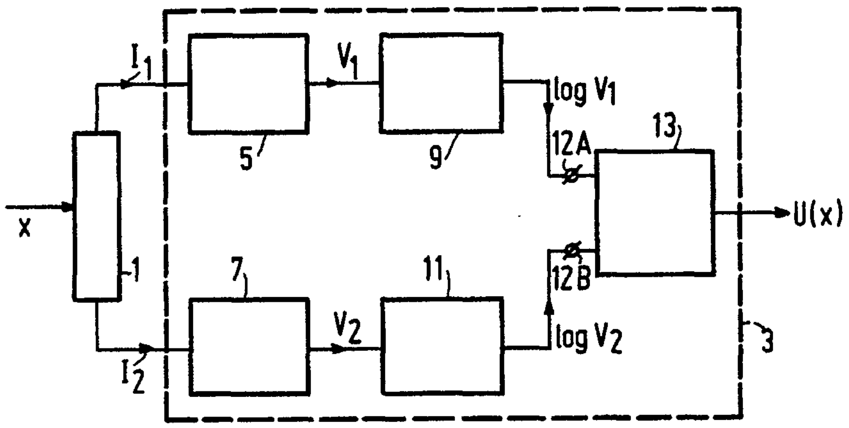

FIG.1

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MEASURING DEVICE.

The invention relates to a measuring device comprising a detector for a quantity x to be measured, which detector is adapted to produce two measuring signals I_1 and I_2 which relate to the quantity x to be measured as $x = (I_1-I_2)/(I_1+I_2)$, which device furthermore comprises a processing circuit ior converting the measuring signals I_1 and I_2 into an output signal U(x) whose value depends on the quantity x to be measured.

An example of such a device is disclosed in Technisches Messen tm, 53 , No. 7/8, pp. 286-292, reference is made notably to Fig. 6 and the associated description. In the cited example the detector is formed by a position-sensitive detector (PSD) which produces two currents I_1 and I_2 as the measuring signals. The processing circuit comprises a subtractor circuit and an adder circuit which supply signals proportional to the difference I_1-I_2 and the sum I_1+I_2, respectively, of the measuring signals. The outputs of these circuits are connected to the inputs of an analog divider which supplies an output signal proportional to $(I_1-I_2)/(I_1+I_2)$. It has been found that the cited processing circuit and similar processing circuits offer satisfactory results if the requirements imposed as regards speed and dynamic range of the measuring system are not particularly severe.

The invention aims to provide a measuring device of the kind set forth which can satisfy very severe requirements as regards speed and dynamic range. To achieve this, the device in accordance with the invention is characterized in that the processing circuit comprises a first and a second logarithmic converter whose inputs are suitable for receiving a first and a second input signal, respectively, which are proportional to the first measuring signal I_1 and the second measuring signal I_2, respectively, its outputs being connected to a first and a second input, respectively, of a subtractor circuit.

In the device in accordance with the invention, the logarithms of the measuring signals are formed directly (possibly after preparation such as current-voltage conversion) resulting in strongly reduced dynamics of these signals. The operation of the logarithmic converters is very fast and the comparatively slow combination of an adder circuit, a subtractor circuit and an analog divider can be dispensed with.

The subtractor circuit succeeding the logarithmic converters supplies an output signal which is proportional to $\log((1+x)/(1-x))$ if no further steps are taken, x being the quantity to be measured. For comparatively small values of x (for example $|x| < 0.6$), approximately:

$$\log \frac{1+x}{1-x} = x$$

Therefore, this output signal can be readily used in many cases. In other cases, however, it may be desirable to have available an output signal which linearly depends on x also for large values of x. Such an output signal is supplied by a preferred embodiment of the device in accordance with the invention which is characterized in that the subtractor circuit is adapted to determine the hyperbolic tangent of the difference between the signals present on its first and its second input.

A further embodiment in which the hyperbolic tangent function is comparatively simply realised in the substractor circuit is characterized in that the subtractor circuit comprises a first and a second bipolar transistor (T_1, T_2) which are connected in a differential amplifier configuration and whose base terminals are connected to the first and the second input, respectively, said transistors being thermally connected to a control circuit for keeping their temperature constant.

These and other aspects of the invention will be described in detail hereinafter with reference to the drawing.

Fig. 1 shows a block diagram of an embodiment of a measuring device in accordance with the invention,

Fig. 2 diagrammatically shows an embodiment of a detector which is suitable for use in the measuring device shown in Fig. 1,

Fig. 3 shows a circuit diagram of an embodiment of a current-voltage converter,

Fig. 4 shows a complete diagram of a current-voltage converter constructed using the principle shown in Fig. 3,

Fig. 5 shows a diagram illustrating the principle of an embodiment of a subtractor circuit, and

Fig. 6 shows a complete diagram of a subtractor circuit constructed on the basis of the principle shown in Fig. 4.

The measuring device which is shown in the form of a block diagram in Fig. 1 comprises a detector 1 for a quantity x to be measured. The detector 1 may be, for example a position sensitive detector as will be described in detail hereinafter with reference to Fig. 2. Other examples in this respect are a dual photocell (duocell) and an optical magnetic field detector as described in EP-A 0 216 163. The detector 1 produces two measuring signals I_1 land I_2 which relate to the quantity x to be measured in accordance with the formule:

$x = (I_1 - I_2)/(I_1 + I_2)$ (1)

In the case of a position sensitive detector, the measuring signals I_1 and I_2 are formed by electric currents. These measuring currents are applied to a processing circuit 3 for converting these currents into an output signal U(x) whose value depends on the quantity x to be measured.

The processing circuit 3 comprises a first current-voltage converter 5 which converts a first measuring current I_1 into a first measuring voltage V_1 and a second current voltage converter 7 which converts the second measuring current I_2 into a second measuring voltage V_2. The measuring voltages V_1 and V_2 are proportional to the currents I_1 and I_2 respectively. The measuring voltages V_1 and V_2 are applied to the inputs of a first logarithmic converter 9 and a second logarithmic converter 11, respectively, whose outputs supply voltages which are proportional to log V_1 and log V_2 respectively. These outputs are connected to the first input 12A and the second input 12B, respectively, of a subtractor circuit 13.

The subtractor circuit 13 may be a simple, known analog subtractor circuit which determines the difference between the two signals present on its inputs 12A and 12B. Because the measuring voltages V_1 and V_2 are proportional to the measuring currents I_1 and I_2, the output signal produced by the subtractor circuit 13 on its output 14 then equals:

$$U(x) = A\log\frac{I_1}{I_2} = A\log\frac{1+x}{1-x} \qquad (2)$$

The value of the output signal U(x) thus logarithmically relates to the quantity x to be measured, A being a proportionality factor. This logarithmic relationship between U(x) and x is acceptable for many applications. However, for other applications a linear relationship will be preferred. In such cases the signal U(x) can be converted, using an arithmetic device (not shown) into a signal which linearly relates to x, for example, by means of a look-up table. However, the subtractor circuit 13 can alternatively be constructed so that the output signal U(x) is proportional to the hypberbolic tangent of the difference between the signals log V_1 and log V_2 present on its two inputs. An example of such a subtractor circuit will be described in detail hereinafter with reference to Fig. 4. Because, generally speaking:

$$\tanh\left[\frac{1}{2}\ \ln\frac{1+y}{1-y}\right] = y \qquad (3)$$

the output signal U(x) is in this case directly proportional to the quantity x to be measured.

Fig. 2 diagrammatically shows a position sensitive detector (PSD) which can be used as a detector in the measuring circuit described with reference to Fig. 1. The PSD consists of a plate 15 of pure silicon which has a thickness of approximately 0.25 mm and on one side of which is provided with a p-layer 17, an n-layer 19 being provided on the opposite side, resulting in a p-i-n structure. At the side of the p-layer the PSD is provided with two measuring contacts 21 and 23 in order to obtain a position-dependent signal. In the present embodiment, the n-layer is provided with a single power supply contact 25. Also known are PSDs comprising two or more contacts on one or on both sides; for example see IEEE Journal of Solid-State Circuits, Vol. SC-13, No 3, pp.392-399. It is to be noted that the dimensions in the vertical direction are strongly exaggerated in Fig. 2.

When a light beam 27 is incident on a point between the two measuring contacts 21 and 23, pairs of charge carriers 29 are generated, which charge carriers reach the measuring contacts 21, 23 and the power supply contact 25, respectively, via the p-layer and the n-layer. When a voltage source 33 of correct polarity is connected between the power supply contact 25 and a reference point 31 and the measuring contacts 21 and 23 are connected to the reference point 31 via ammeters 35 and 37, the charge carriers 29 generated cause a photocurrent I_{ph} from the positive pole of the voltage source 33 to the power supply contact 25. This photocurrent is distributed between the measuring contact 21 and 23, so that the ammeters 35 and 37 measure measuring currents I_1 and I_2, respectively, for which $I_1 + 12 = I2_{ph}$. The value of the measuring currents I_1 and I_2 depends on the location in which the light beam 27 is incident on the layer 17.

The measuring contacts 21 and 23 aze situated at a distance L from the centre M of the PSD and the light beam 27 is incident on the layer 17 at a distance d from the centre, where d may vary from +L (the light beam is incident on the PSD near the left hand measuring contact 21) to -L (the light beam is incident on the PSD near the right hand measuring contact 23). The measuring currents I_1 and I_2 then equal

$I_1 = I_{ph}(1+d/L)/2$ (4)

$I_2 = I_{ph}(1-d/L)/2$ (5)

The equation (1), Where $d/L=x$, is obtained by dividing the difference of the equations (4) and (5) by their sum.

It follows from the foregoing that the operation of the PSD is analogous to that of a potentiometer whose wiper is connected to a current source while its fixed contacts are connected to a reference point. The position of the wiper can be rendered dependent on a quantity to be measured (for example, a pressure or a temperature) and the potentiometer can be inserted as the detector 1 in the measuring device shown in the Figure. The PSD can similarly be used as a detector, for example in a distance meter as described in the cited article in Technisches Messen tm, 53 , No. 7/8.

When, as in the case of a PSD, the measuring signals I_1 and I_2 are measuring currents, it is generally desirable to convert these signals into measuring voltages V_1 and V_2 prior to further processing. For this purpose use is made of the current-voltage converters 5 and 7 which may consist, for example of an operational amplifier with feedback, the measuring current being applied to the inverting input (see, for example ATM, Blatt Z 6343-9 (July 1973), page 137, Fig. 1). A drawback of this solution consists in that, due to the parasitic capacitance of the feedback resistance (which is chosen to be large for considerations of noise), the bandwidth is limited to a few MHz. Therefore, use is preferably made of a low-noise current amplifier, for example as described in Electronica 83/20 (October 21, 1983), pp 39-49. The principle of the circuit is shown in Fig. 3. When the gain of the amplifier 39 is infinitely high and when $Z_1 \gg Z_0$, $I_u = Z_1/Z_0 . I_i$. When I_u is guided through a suitable resistance, a voltage is obtained which is proportional to I_u and hence to I_i.

Fig. 4 shows a complete diagram of an embodiment of the first current voltage converter 5 which is constructed in accordance with the principle shown in Fig. 3. Z_1 is the parallel connection of R_{35}, C_{12} and the parasitic capacitance of R_{35} which amounts to approximately 0.2 pF. Z_0 is the network consisting of R_{46}, R_{47}, R_{48} and C_{24}, R_{46} and R_{48} being small with respect to R_{47} so that Z_0 is determined mainly by R_{47} and C_{24}. It appears from the cited article in Electronica that the current amplification of the circuit is substantially independent of the frequency when the ratio Z_1/Z_0 is a real number (in the circuit in accordance with Fig. 3). This is the case when the RC products of these two impedances are equal. In the circuit shown in Fig. 4 R_{35} equals 100 kΩ and C_2 equals 1 pF, so that the RC product of Z_1 (taking into account the parasitic capacitance of 0.2 pF) equals 1.2×10^{-7}. R_{47} equals 1 kΩ and C_{24} equals 120 pF, so that the RC product of Z_0 also equals 1.2×10^{-7}. The ratio Z_1/Z_0 then equals $C_{24}/(C_2 + 0.2\text{ pF}) = 100$.

The values and the type numbers of the components used in a practical embodiment of the circuit shown in Fig 4 are:

R_{31}: 22 Ω
R_{32}: 270 Ω
R_{33}: 100 Ω
R_{34}: 1 MΩ
R_{35}: 100 kΩ
R_{36}: 1 MΩ
R_{37}: 4.7 kΩ
R_{38}: 75 Ω
R_{39}: 1 kΩ
R_{40}: 33 kΩ
R_{41}: 470 Ω
R_{42}: 2.7 kΩ
R_{43}: 4.7 kΩ
R_{44}: 10 kΩ
R_{45}: 820 Ω
R_{46}: 33 Ω
R_{47}: 1 kΩ
R_{48}: 51 Ω
D_1: BZX 79C15
A_1: AD 548
C_{11} : 220 nF

C_{12} : 1 pF
C_{13} : 220 nF
C_{14} : 25 pF
C_{15} : 10 nF
C_{16} : 100 nF
C_{17} : 10 nF
C_{18} : 33 nF
C_{19} : 100 nF
C_{20} : 100 nF
C_{21} : 220 nF
C_{22} : 220 nF
C_{23} : 100 nF
C_{24} : 120 pF
C_{25},C_{26}: 2.2 µF
T_{11} : SST 4416
T_{12} : BF 840
T_{13} : BF 550
T_{14},T_{16}: BC 856
T_{15} : BC 846

The detector 1 is accommodated, together with T_{11}, R_{34}, C_{12}, R_{35} and corresponding components of the second current/voltage converter 7 (not shown), on a first printed circuit board 41, the further components of the first current/voltage converter 5 being accommodated on a second board 43. For the second current/voltage converter 7 there is provided a second board (not shown) which corresponds to the board 43. The output current I_u of the circuit (see Fig. 3) is converted, by way of the resistance R_{48}, into an output voltage which is applied to the first logarithmic converteter 9

In this configuration the noise level amounts to 8 nA in a bandwidth of 20 MHz. The maximum input current I equals 800 µA, so that the total dynamic range equals 100 dB.

Each of the logarithmic amplifiers 9 and 11 may consist of a known circuit whose principal component is formed by a logarithmic amplifier (for example, of the type AD 640 manufactured by Analog Devices) or a cascade connection of two of such amplifiers.

Fig.5 shows a diagram illustrating the construction principle of a circuit which is suitable for use in the subtractor circuit 13 in order to make this subtractor circuit suitable for determining the hyperbolic tangent of the difference between the signals present on its first and second inputs 12A and 12B, respectively. The circuit comprises two identical bipolar transistors T_1 and T_2 which are connected in a differential amplifier configuration. The transistors T_1 and T_2 are maintained at the same constant temperature. The base terminals receive voltages V'_1 and V'_2, respectively, which are proportional to the logarithms of the measuring voltages V_1 and V_2, respectively. The emitter terminals are connected together to a current source 53, valued I_0. The operation is as follows:

Generally speaking, for a bipolar transistor:

$$I_C=i_S\{\exp\left(\frac{qV_{BE}}{kT}\right)-1\} \tag{6}$$

Therein:
I_c is the collector current
i_s is a leakage current proportional to the emitter surface,
q is the unity charge
k is Boltzmann's constant
T is the absolute temperature
V_{BE} is the base-emitter voltage.
Because i_s and T are the same for both transistors T_1 and T_2 and because

$\exp\left(\frac{qV_{BE}}{kT}\right) >> 1$, it follows from (6) that:

$$\frac{Ic1}{Ic1} = \exp\left\{\frac{q}{kT}(V_{BE1} - V_{BE2})\right\} = \exp\left\{\frac{q}{kT}(V'_1 - V'_2)\right\} \qquad (7)$$

Therein, the suffices 1 and 2 refer to the transistors T_1 and T_2, respectively. Because, furthermore $I_0 = I_{c1} + I_{c2}$, it follows from (7) that:

$$\frac{I_{c1} - I_{c2}}{I_0} = \frac{\exp\left\{\frac{q}{kT}(V'1 - V'2)\right\} - 1}{\exp\left\{\frac{q}{kT}(V'1 - V'2)\right\} + 1} = \tanh\left\{\frac{q}{kT}(V'1 - V'2)\right\}$$

Therefore

$$I_{c1} - I_{c2} = I_0 \cdot \tanh\left\{\frac{q}{kT}(V'_1 - V'_2)\right\} \qquad (8)$$

It follows from (8) and (3) that the collector difference current I_{c1}-I_{c2} in the circuit shown in Fig. 4 is proportional to the quantity x to be measured.

Fig. 5 shows a complete diagram of an embodiment of subtractor circuit utilising the principle shown in Fig. 4. The transistors, connected in a differential amplifier configuration, are again denoted by the references T_1 and T_2 in Fig. 5. The first input 12A is connected to the output of the first logarithmic converter 9 and the second input 12B is connected to the output of the second logarithmic converter 11. The collector difference current of the transistors T_1 and T_2 is converted, using the operational amplifiers denoted by the references IC2 and IC3, into an output voltage u(x) which varies between 0 and 2 V and which is proportional to the quantity x to be measured. The emitter voltage of the transistors T_1 and T_2 is proportional to the logarithm of the sum of the measuring signals I_1 and I_2, and hence to I_{ph}, if the detector 1 is a PSD as described with reference to Fig. 2. This emitter voltage is amplified by means of the operational amplifier IC5 and is available, via a second output 14′ of the subtractor circuit 13, as a second output voltage u(i).

The temperature of the described subtractor circuit 13 is maintained at a constant value (approximately 50° C) by a control circuit 55 which is thermally connected to the subtractor circuit. This control circuit comprises a transistor T_3 which acts as a temperature sensor and whose output signal is amplified by the operational amplifier IC4 which controls the transistors T_4 and T_5 which act as heating elements. The control circuit 55 is preferably accommodated in an envelope together with the subtractor circuit. The values and type numbers of the components used in a practical embodiment of the circuit shown in Fig. 5 are:

R_1,R_2: 33 Ω
R_3,R_4: 16.2 Ω
R_5,R_6: 100 kΩ
R_7 : 1 MΩ
R_8 : 10 kΩ
R_9 : 7.5 kΩ
R_{10} : 100 kΩ
R_{11} to R_{14}: 1 kΩ
R_{15} : 470 kΩ
R_{16},R_{17}: 1 kΩ

R_{18} : 50 Ω
R_{19} : 3 kΩ
R_{20} : 100 Ω
R_{21}: 1 kΩ
R_{22}: 50 Ω
P_1 : 5 kΩ
P_2 : 2 kΩ
P_3 :100 kΩ
P_4 : 5 kΩ
P_5 :500 Ω
C_1 : 10 nF
C_2 : 1 nF
C_3 : 22 nF
C_4 : 2.2 nF
T_1 to T_5: CA3127
T_6,T_7 : BF256A

Claims

1. A measuring device comprising a detector (1) for a quantity x to be measured, which detector is adapted to produce two measuring signals I_1 and I_2 which relate to the quantity x to be measured as $x = (I_1-I_2)/(I_1+I_2)$, which device furthermore comprises a processing circuit (3) for converting the measuring signal I_1 and I_2 into an output signal U(x) whose value depends on the quantity x to be measured, characterized in that the processing circuit (3) comprises a first and a second logarithmic converter (9, 11) whose inputs are suitable for receiving a first and a second input signal, respectively, which are proportional to the first measuring signal I_1 and the second measuring signal I_2, respectively, its outputs being are connected to a first and a second input (12A, 12B), respectively, of a subtractor circuit (13).

2. A measuring device as claimed in Claim 1, characterized in that the subtractor circuit (13) is adapted to determine the hyperbolic tangent of the difference between the signal present on its first and its second input (12A, 12B).

3. A measuring device as claimed in Claim 2, characterized in that the subtractor circuit (13) comprises a first and a second bipolar transistor (T_1, T_2) which are connected in a differential amplifier configuration and whose base terminals are connected to the first and the second input (12A, 12B), respectively, said transistors being thermally connected to a control circuit (55) for keeping their temperature constant.

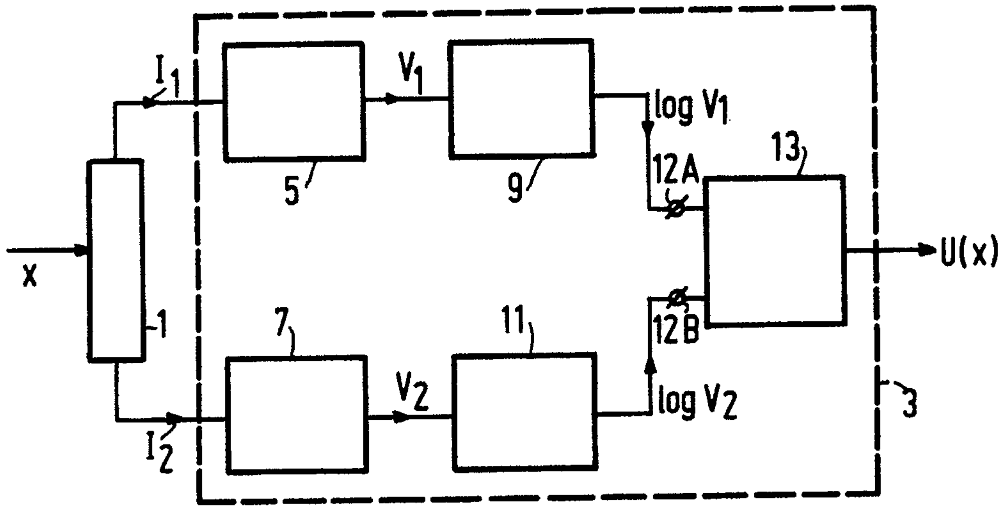

FIG.1

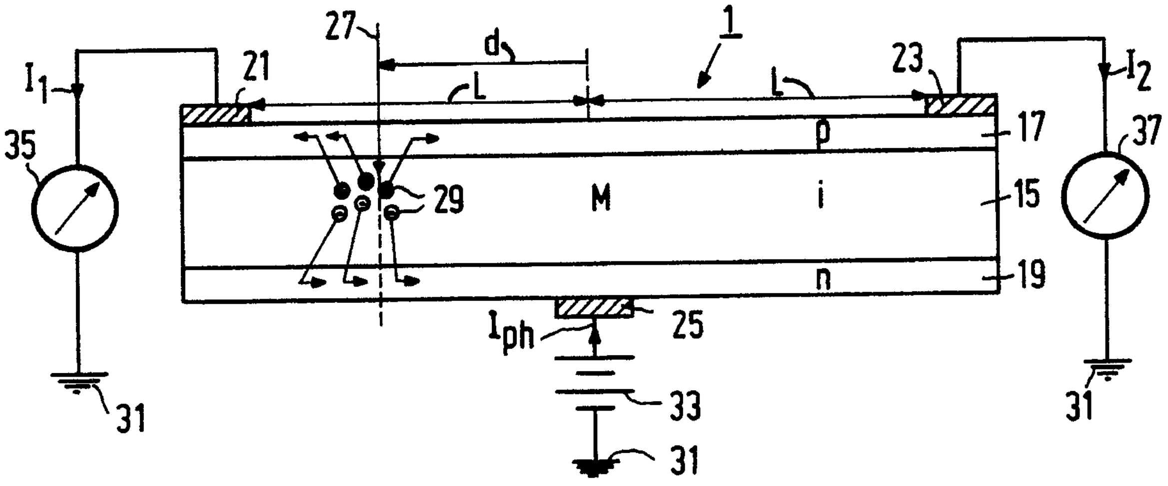

FIG.2

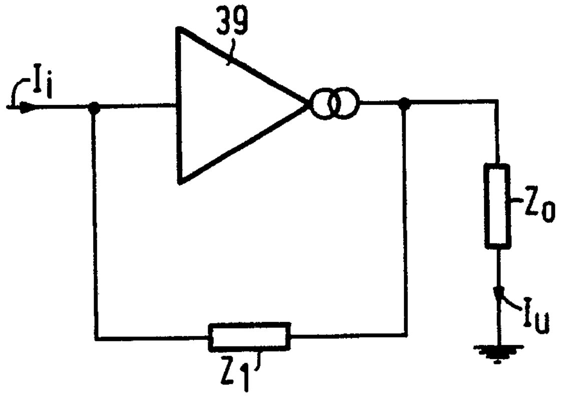

FIG.3

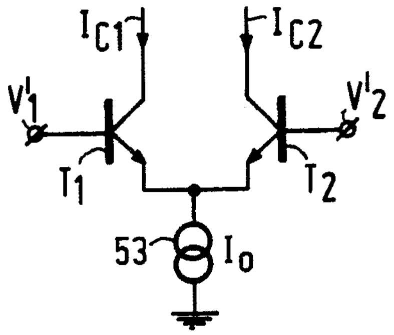

FIG.5

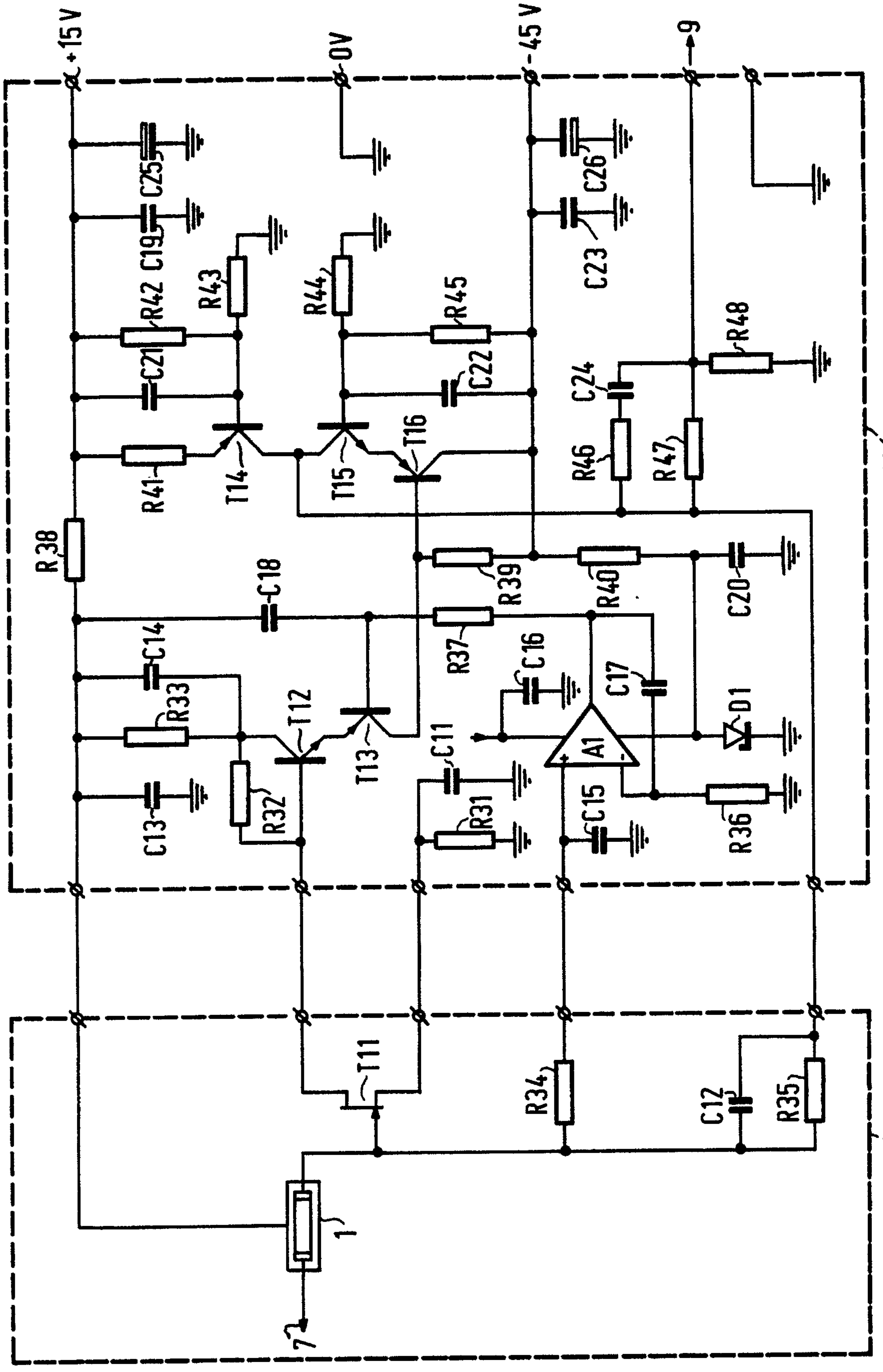

FIG.4

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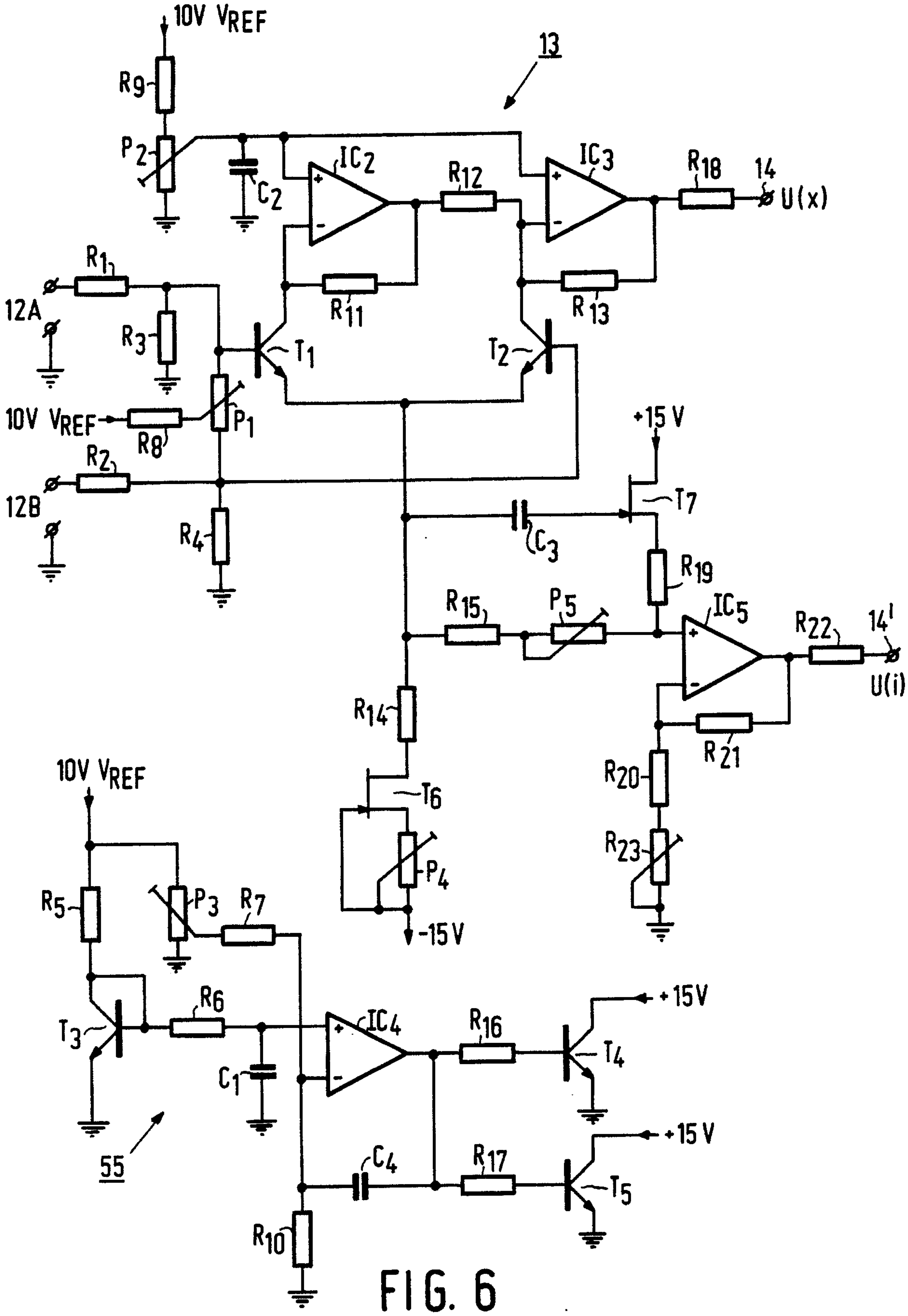

FIG. 6

3-III-PHN 13092

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EUROPEAN SEARCH REPORT

Application Number

EP 90 20 2528

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-4 827 120 (HONEYWELL) * Column 4, lines 3-44; column 5, lines 18-45 * ---	1,3	G 01 D 5/26
A	GB-A-1 426 011 (INSTITUT POLUPROVODNIKOV) * Page 3, line 5 - page 4, line 7 * ---	1,3	
A	RADIO FERNSEHEN ELEKTRONIK, vol. 37, no. 2, 1988, pages 85-87; T. GÜNTHER: "Einsatzmöglichkeiten positionsempfindlicher Si-Fotodioden" * Pages 85-87 * ---	1	
A	MEASUREMENT, vol. 6, no. 1, January-March 1988, pages 5-9; B. SCHMIDT et al.: "Hybrid integrated sensor for position measurment" * Pages 5-9 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G 01 D 5

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26-10-1990	RAMBOER P.

CATEGORY OF CITED DOCUMENTS

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